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In this section we summarize our research accomplishment under this grant. Our research achievements can be categorized conveniently into five areas: reliability, dependence concepts, applications of dependence concepts, time series, and other research. Keywords: Mathematical modeling, modeling, theory. (KT)

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FINAL TECHNICAL REPORT
FOR AFOSR GRANT AFOSR 84-0113
Principal Investigators: Henry W. Block, Allan R. Sampson, Thomas H. Savits

1. SUMMARY OF RESEARCH

In this section we summarize our research accomplishments under this grant. Our research achievements can be categorized conveniently into five areas: reliability, dependence concepts, applications of dependence concepts, time series, and other research.

A. Reliability

Under this grant, various topics in reliability theory have been studied. These include multivariate nonparametric classes, maintenance models and multistate structures.

In technical report 85-01, recent research in multivariate nonparametric life classes in reliability is surveyed. The multivariate aging notions of IFR, IFRA, NBU, DMRL, and HNBUE are discussed and some of their relationships and properties are presented. It is shown in technical report 84-05 that the IFRA scaled-mins class is closed under convolution. A multivariate distribution function of n components subjected to shocks from a nonhomogeneous Poisson process is considered in report 85-07. It is shown that if the distribution function of the time until the first shock is IFR, IFRA, or NBU, then the multivariate lifelengths of the n components belongs to a corresponding multivariate IFR, IFRA, or NBU class.

A survey of the recent research concerning maintenance policies is presented in technical report 84-04. Some stochastic comparisons on the number of failures and removals in [0,s] for a complete repair model under age and block replacements are obtained in 86-08. These results are extended for the block policy case in technical report 88-06 in which stochastic comparisons of entire processes are obtained for the complete repair model as well as for the minimal repair model. The technical reports 87-06 and 88-01 consider a very general cost structure for a maintained system. The first report obtains a cost relationship between the age and block policies; the second extends the relationship to

include discounting.

In technical report 86-06 characterizations of nonhomogeneous Poisson processes in terms of cumulants and increments of the counting process are obtained. An estimate of the stable availability for a series system is considered in 87-02. Some related asymptotic normality and rates of convergence are also discussed. Technical report 87-03 investigates a class of multistate systems which are more series-like or more parallel-like. Some closure properties are presented as well as some characterization results. Some improved reliability bounds for systems with dependent components are derived in technical report 87-10.

B. Dependence Concepts

Under the grant, concepts of positive dependence, negative dependence, monotone correlation and some applications have been studied.

Technical report 84-01 presents a unified framework for studying and relating positive dependence orderings, positive dependence properties and measures of positive dependence. The latter two new concepts are formally defined, their properties are discussed and interrelationships among these three concepts are given. In technical report 85-05 the concepts of conditionally more positively quadrant dependent and conditionally more dispersed are introduced and studied. The report also considers other conditional positive dependence concepts. In technical report 85-10a representations of upper sets contained in a finite two or three dimensional discrete lattice are presented. These representations are then used for a variety of applications in multivariate positive dependence. In technical report 86 -07, the nonparametric maximum likelihood estimators of two multivariate c.d.f.'s F and G are obtained under the constraint that F is stochastically larger than G. New higher order two and three dimensional product-type lower bounds are obtained for certain multivariate probabilities in technical report 88-08. The positive dependence conditions sufficient for these bounds to hold are described and exemplified by the multivariate normal and Marshall-Olkin exponential distributions. In technical

report 87-05, a variety of new dependence notions are given to describe the dependence relationships between two or more sets of variables. Under a variety of different notions of setwise dependence, various characterizations of setwise independence are described in technical report 87-04.

Technical report 84-02 studies random vectors conditioned on events involving their order statistics. The conditioning events considered occur naturally in reliability theory. It is shown that these conditional random vectors are negatively dependent in a very strong sense. In technical report 84-03 a concept of negative dependence by stochastic ordering is introduced. It is shown that three models of negative dependence satisfy it, and that it is satisfied by some frequently used multivariate d.f.s. Technical report 85-05 considers conditional negative dependence concepts and some of their applications.

In technical report 85-10b a generalization of the Hoeffding-formula for multivariate cumulants is presented. This result is then used to characterize independence. Relationships with various types of dependence are also given. In technical reports 86-03 and 86-04, a bivariate random vector assuming values in a bivariate lattice is considered. The probabilities of this bivariate random vector are presented as a matrix and a new matrix decomposition of Q is obtained. This decomposition is applied to various concepts in positive dependence. Furthermore, a number of results concerning the concordant monotone correlation and the sup-correlation are presented. Additionally considered are applications of these ideas to Hotelling's canonical correlation and to other monotone correlations.

A number of research efforts concerned various positive dependence notions for bivariate and, more generally, multivariate empirical c.d.f.'s. Through invariance arguments, it was shown that these notions can be studied on S_n, the set of all permutations of $\{1, \ldots, n\}$. In technical report 87-09, a variety of partial orderings on S_n are considered and shown to be related to certain positive dependence orderings on bivariate c.d.f.'s. The concepts are further amplified upon in technical report 88-10. In technical report 88-09, certain subsets of $S_n^2 \equiv S_n \times S_n$, and S_n^k are characterized and shown to correspond to certain multivariate positive dependence concepts. A description and characterization

of some of the partial orderings on S_n by means of metrics on S_n is given in technical report 87-11.

C. Applications of Dependence Concepts

One of the focuses of the research in our grant concerning dependence is on the applicability of these notions to statistical and data analytical issues.

Technical report 85-03 employs positive dependence concepts and orderings to compare and evaluate four simultaneous confidence interval procedures for estimable functions in the general linear model. The probability inequalities of technical report 88-08 are used in technical report 88-07 to develop an "optimized" product-type probability bound which is important in a variety of applications, e.g., change point detection and group sequential trials. Under commonly occuring positive dependence structures, this new bound is shown to be superior to previously obtained optimized Bonferroni-type bounds of Hunter and Worsley. In technical report 87-08, some recent multivariate probability inequalities are used to obtain simultaneous inference procedures consistent with the Benard-van Elteren nonparametric procedure, which is used to compare multiple treatments, in the presence of blocking effects and possibly unequal sample sizes. Technical report 85-09 utilizes notions of monotone correlation to develop a methodology to merge in a unidimensional scale, judgements of two evaluators whose opinions (possibly on dissimilar scales) about N objects are given in bivariate ordinal contingency table form.

Two other research efforts focus on the application of the notions of association and positive quadrant dependence to ordinal contingency tables and bivariate empirical distributions. In technical report 88-03, an efficient computational algorithm is given for checking association in bivariate ordinal contingency tables. For even moderate sized tables, this algorithm is shown to reduce the computational effort by potentially several orders of magnitude. Technical report 88-04 gives a new characterization for bivariate empirical distributions to be positively quadrant dependent. Based upon this characterization, efficient graph-theoretic algorithms are given to enumerate and generate all positively quadrant

dependent empirical distributions of a fixed sample size.

D. Time Series

Another area of research for this grant has been times series with particular attention to modeling nonnormal multivariate processes.

These accomplishments in time series are given in four technical reports. In technical reports 85-02 and 86-01 various time series with bivariate exponential and geometric marginals are presented. It is shown that dependency on the past is relatively simple and explicit. The theory of positive dependence is used to obtain association between random vectors. Special cases of these processes are stationary with well known bivariate exponential and geometric distributions. A similar project involving Dirichlet distributions is reported on in report 87-01. In 87-07 a more general case with arbitrary continuous marginals is studied.

E. Other Research

A number of other various research topics were investigated, in part, by co-researchers and visiting researchers who participated in our grant. These are now summarized.

In technical report 85-04 log-linear models are applied to ordinal longitudinal data, which were collected to study the mental health effects of the Three Mile Island nuclear accident. Technical report 85-06 proposes a new method for assessing degree of agreement among raters, and discusses the advantages of this method. In technical report 85-08 a methodology for determining standards based on multivariate tolerance regions is presented. Their use in quality control is discussed. In technical report 85-11 the question of the effect of adenoidectomy on the bearing loss of children with SOM is addressed from the statistical point of view, and in technical report 85-12 the issue of evaluation of scientific information is addressed using statistical methodology. Technical report 85-13 presents the cross prediction problem in a general linear regression model. Generalizations of this problem are discussed and applications are illustrated. In technical report 85-14 two characterizations for linear

exponential families are presented. Technical report 86-02 analyzes randomized cloud seeding data. Technical report 86-05 presents an alternative method for obtaining M.L.E estimates in the discrete time mover-stayer model, and illustrates the results with a data application. A review of *Multiple Interpretation of Clinical Laboratory Data* by A. Albert and E. K. Harris (1987) appears in report 87-12. Technical report 87-02 gives exact power and sample size calculations for planning and design of observational studies. In technical report 88-05 the reliability of a cytolytic assay performed at the Pittsburgh Cancer Institute is described and discussed.

2. VISITORS

During the grant period May 1984 to present, a large number of researchers have visited for various time periods. A list of these visiting scholars with their affiliation and visit dates is as follows:

M. Abdel-Hammed (University of Kuwait)	August 2-11, 1984
M. Bhattacharjee (Indian Institute Management)	July 2-4, 1984
P. Boland (University College, Dublin)	June 9-15, 1985
J. Bryant (University of Cincinnati)	September 1987 - August 1988
S. Cambanis (University of North Carolina)	March 31, 1988
D. Chhetry (Katmandu University)	September 1, 1985-Augst 31, 1987
M. L. Eaton (University of Minnesota)	February 5, 1988
E. El-Neweihi (University of Illinois, Chicago)	July 2-4, 1984; May 13-17, 1986
E. Enns (University of Calgary)	October 10-11, 1985
Z. Fang (University of Pittsburgh)	September 1, 1986-August 31, 1987
C. Fuchs (Tel-Aviv University)	September 1, 1985-May 31, 1986
W. Griffith (University of Kentucky)	July 22-August 1, 1984; July 10-12, 15-17, 1985; May 19-22, 1986
G. Kimeldorf (University of Texas, Dallas)	July 18-20, 1984

N. Langberg (Haifa University)	June 15-August 31, 1984; February 1-March 1, 1985; June 1-July 1, 1985; February 1-March 1, 1986; September 1, 1986-August 31, 1987 May - July 1988
M.-L. Lee (Boston University)	June 24-July 7, 1984; July 21-26, 1985
S. May (Carnegie-Mellon University)	September 1, 1985-April 30, 1986
T. Nguyen (Bowling Green University)	June 26-July 7, 1986
B. Schweitzer (University of Massachusetts)	October 1987
M. Shaked (University of Arizona)	December 7, 1987
N. Singpurwalla (George Washington University)	November 14-16, 1985
E. Sungar (Carnegie-Mellon University)	January 1-May 31, 1986
J. Tiago de Oliveira (Academy of Sciences of Lisbon)	July 1, 1987
G. Tsaturyan (Florida State University)	April 1988
L. Whitaker (University of CA, Santa Barbara)	July 1, 1985-March 31, 1986 July 11-16, 1986

3. TITLES AND ABSTRACTS OF TECHNICAL REPORTS

REPORT NO.	TITLE	AUTHOR(S)

84-01   A FRAMEWORK FOR POSITIVE DEPENDENCE   George Kimeldorf
                                                          Allan R. Sampson

Abstract - This paper presents for bivariate distributions a unified framework for studying and relating three basic concepts of positive dependence. These three concepts are positive dependence orderings, positive dependence properties and measures of positive dependence. The latter two concepts are formally defined and their properties discussed. Interrelationships among these three concepts are given, and numerous examples are presented.

84-02   PROBABILITY INEQUALITIES VIA NEGATIVE   Henry W. Block
              DEPENDENCE FOR RANDOM VARIABLES   Vanderlei Bueno
              CONDITIONED ON ORDER STATISTICS   Thomas H. Savits
                                                            Moshe Shaked

Abstract - Distributions are studied which arise by considering independent and identically distributed random variables conditioned on events involving order statistics. It is shown that these distributions are nega- tively dependent in a very strong sense. Furthermore, bounds are found on the distribution functions. The conditioning events considered occur naturally in reliability theory as the time to system failure for k-out-of-n systems. An application to systems found with "second-hand" components is given.

84-03   A CONCEPT OF NEGATIVE DEPENDENCE   Henry W. Block
              USING STOCHASTIC ORDERING   Thomas H. Savits
                                                        Moshe Shaked

Abstract - A concept of negative dependence called negative dependence by stochastic ordering is introduced. This concept satisfies various closure properties. It is shown that three models for negative dependence satisfy it and that it implies the basic negative orthant inequalities. This concept is also satisfied by the multinomial, multivariate hypergeometric, Dirichlet and Dirichlet compound multinomial distributions. Furthermore, the joint distribution of ranks of a sample and the multivariate normal with non- positive pairwise correlations also satisfy this condition. The positive dependence analog of this condition is also studied.

84-04   ΓREVENTIVE MAINTENANCE POLICIES   Henry W. Block
Wagner S. Borges
Thomas H. Savits

Abstract - Recent research concerning maintenance policies with time dependent cost and probabilities is surveyed.

84-05   CONVOLUTION OF THE IFRA SCALED-MINS CLASS   Emad El-Neweihi
Thomas H. Savits

Abstract - The class of nonnegative random vectors $\underline{T} = (T_1, \ldots, T_n)$ for which $\min\limits_{1 \leq i \leq n} a_i T_i$ is IFRA for all $0 < a_i \leq \infty$, $i = 1, \ldots, n$, is closed under convolution.

85-01   MULTIVARIATE NONPARAMETRIC CLASSES   Henry W. Block
IN RELIABILITY   Thomas H. Savits

Abstract - Recent research in multivariate nonparametric classes in reliability is surveyed.

85-02   MOVING AVERAGE MODELS WITH BIVARIATE   Naftali A. Langberg
              EXPONENTIAL AND GEOMETRIC DISTRIBUTION   David S. Stoffer

Abstract - Two classes of finite and infinite moving average sequences of bivariate random vectors are considered. The first class has bivariate exponential marginals while the second class has bivariate geometric marginals. The theory of positive dependence is used to show that in various cases the two classes consist of associated random variables. Association is then applied to establish moment inequalities and to obtain approximations to some joint probabilities of the bivariate processes.

85-03   SIMULTANEOUS CONFIDENCE INTERVALS   Camil Fuchs
              FOR THE GENERAL LINEAR MODEL   Allan R. Sampson

Abstract - This paper describes, compares and illustrates four known simultaneous confidence interval procedures for the general linear model. It is shown that three of the four procedures can be ordered by the increasing length of their confidence intervals as follows: (I) Sidak multivariate t-distribution intervals, (II) Sidak independent t-distribution intervals, and (III) Bonferroni intervals. There is no uniform ordering between the confidence intervals yielded by the fourth procedure (Schefffe) and the other three; these relationships are explored numerically.

85-04   ORDINAL LOG-LINEAR MODELS AND THE TMI DATA   Sherryl May

Abstract - Log-linear models appropriate for data arranged in ordinal contingency tables have been proposed and discussed by authors such as Fienberg (1982) and Agresti (1983). Such models are applied to ordinal longitudinal data collected on the subject of possible mental health effects of the Three Mile Island nuclear accident. The results are discussed.

85-05   CONDITIONALLY ORDERED DISTRIBUTIONS   Henry R. Block
                                                     Allan R. Sampson

Abstract - The concepts of conditionally more positively quadrant dependent, and conditionally more dispersed are introduced and studied. Based on these two concepts, new conditions are given for multivariate c.d.f.'s F and G so that $E_F h(X) \geq E_G h(X)$ for suitable $h(X)$. Special cases include the multivariate normal distribution and elliptically contoured distributions. Conditional positive and negative dependence concepts as well as applications to the Farlie Gumbel-Morgenstern distribution are also considered.

85-06   MODELLING INTER-RATER AGREEMENT   Sherryl May
                WITH ORDINAL LOG-LINEAR MODELS

Abstract - A new method for assessing the degree of agreement among raters is proposed. This method makes use of the recently-developed methodology of ordinal log-linear models. The advantages of this new method are discussed and explained. Several examples of the implementation of the method are then presented.

85-07   SOME MULTIVARIATE DISTRIBUTIONS DERIVED   Thomas H. Savits
                FROM A NONFATAL SHOCK MODEL

Abstract - A nonhomogeneous Poisson shock model has a continuous mean function $\Lambda(t)$. The kth shock S_k causes simultaneous failure of the components $j \in J \subset \{1, \ldots, n\}$ with probability $p_j(S_k)$. If T_j is the lifetime of component j, it is shown that $(\underline{T}_1, \ldots, T_n)$ belongs to various multivariate nonparametric life classes depending on the life class of $\overline{F}(t) = \exp\{-\Lambda(t)\}$.

85-08   MULTIVARIATE TOLERANCE REGIONS AND F-TEST   Camil Fuchs
                                                                    R. Kenett

Abstract - The determination of standards or norms is a central issue in quality control procedures. In this article we present a methodology for determining standards based on multivariate tolerance regions. We study the correspondance between the F-test at significance level α and tolerance regions with parameters (Γ, δ).
The methodology and statistical issues arising from its application are illustrated with two real data problems. In both cases the attributes of the tested elements are compared with tolerance regions obtained from a reference sample. In the first example, both the tested elements and the reference sample originate from the same target ("in control") population. The significance levels of the resulting tests are estimated by a crossvalidation procedure. The tested elements in the second sample are from an "out of control" process. The percent of elements detected as not belonging to the target population constitutes, in that case, the empirical power of the test.

85-09 MERGING DISSIMILAR ORDINAL Jerrold H. May
CATEGORICAL JUDGMENTS Allan R. Sampson

Abstract - Two judges are presented with N objects and are asked separately to evaluate each object according to a fairly specific qualitative criterion. Each judge is allowed to develop his own unique ordinal categorical scale. Thus the data consists of N pairs of ordinal categorical data on dissimilar scales. We give an approach which merges the separate bivariate ordinal scales into a single numerical value providing a rank order of all N objects. To do so, a model is first postulated, and its parameters are estimated using a technique involving the non-linear minimization of a certain natural squared error optimality criterion. The computational aspects of this optimization are discussed. The procedure is applied to a large data set involving financial evaluation.

85-10a POSITIVE DEPENDENCE. UPPER SETS, Allan R. Sampson
AND MULTIDIMENSIONAL PARTITIONS Lyn R. Whitaker

Abstract - Let U be an upper set contained in the finite discrete lattice $L = \{1, \ldots, D(1)\} \times \cdots \times \{1, \ldots, D(p)\}$. Representations for U are obtained and shown to correspond to certain multidimensional partitions of integers. It is shown that for p=3, the number of possible upper sets in L is $\prod_{i=0}^{D(3)-1} \binom{D(1)+(D(2)+i}{D(1)} / \binom{D(1)+i}{D(1)}$. Various other representation and enumeration results are obtained for related settings. Considered are a variety of applications to multivariate positive dependence and various notions in statistics and reliability theory.

85-10b A MULTIVARIATE EXTENSION Henry W. Block
OF HOEFFDING'S LEMMA Zhaoben Fang

Abstract - Hoeffding's Lemma gives an integral representation of the covariance of two random variables in terms of difference between their joint and marginal probability functions, i.e.,

$$Cov(X,Y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \{P(X > x, Y > y) - P(X > x)P(Y > y)\}dxdy .$$

This identity has been found to be a useful tool in studying the dependence structure of various random vectors. A generalization of this result for more than 2 random variables is given. This involves the following integral representation of the multivariate joint cummulart for r > 1:

$$Cum(X_1, \ldots, X_r) = \int \cdots \int Cum(\chi_{X_1}(x_1), \ldots, \chi_{X_r}(x_r))dx_1 \cdots dx_r$$

where $\chi_{X_i}(x_i) = 1$ if $X_i > x_i$, 0 otherwise. Applications of this result include characterizations of independence. Relationships with various types of dependence are also given.

85-11 ADENOIDECTOMY VERSUS VT Camil Fuchs

Abstract - This article focuses on the question of the effect of adenoidectomy on the hearing loss of children with SOM. The empirical results originate from a recent study which considers various facets related to theory that correlates adenoidectomy with the cure of SOM and AOM. The question of hearing loss is one of the five hypotheses addressed in that study Here we focus on the models, on the assumptions and on the empirical results from several studies. The results from three original studies are cross validated with those from other published investigations.

85-12 EVALUATION OF SCIENTIFIC INFORMATION Camil Fuchs

Abstract - This paper deals with issues of evaluation of scientific information from a statistical viewpoint and was presented at the International Symposium on Acute and Secretory Otitis Media.

85-13 AN INTERPRETATIVE FRAMEWORK FOR Allan R. Sampson
REGRESSION AND LINEAR PREDICTION David S. Stoffer

Abstract - When $(X,Y)'$ $N((\mu_1,\mu_2)', \Sigma)$, Σ positive definite, the values of α,β which minimize the weighted risk $E\{w[Y-(\alpha+\beta X)]^2 + (1-w)[X-(Y-\alpha)/\beta]^2\}$ are obtained. This is termed the cross-prediction problem. Generalizations of this problem are presented and related to other regression and multivariate techniques such as principal components, thereby providing a unified framework for many of these concepts. The various generalizations are examined in detail and illustrated in applications to a well known data set.

85-14 ON THE LINEAR EXPONENTIAL FAMILY Naftali A. Langbert
WITH A QUADRATIC VARIANCE FUNCTION Osnat Stramer

Abstract - It is shown that for every triple (A,B,D), $A > 0$ and $B^2 - 4AD < 0$ there is a linear exponential family (LEF) of distributions s.t. its variance, as a function of the mean (μ), is given by $A\mu^2 + B\mu + D$. It's also shown that if for a triple (A,B,D), $A < 0$ and $B^2 - 4AD > 0$ there is a LEF with variance function equal to $A\mu^2 + B\mu + D$ then $-A^{-1}$ is a positive integer and the LEF is a linear transformation of a binomial LEF.

86-01   BIVARIATE EXPONENTIAL AND GEOMETRIC   Henry W. Block
AUTOREGRESSIVE AND AUTOREGRESSIVE   Naftali A. Langberg
MOVING AVERAGE MODELS   David S. Stoffer

Abstract - We present autoregressive (AR) and autoregressive moving average (ARMA) processes with bivariate exponential (BE) and bivariate geometric (BG) distributions. The theory of positive dependence is used to show that in various cases, the BEAR, BGAR, BEARMA, and BGARMA models consist of associated random variables. We discuss special cases of the BEAR and BGAR processes in which the bivariate processes are stationary and have well known bivariate exponential and geometric distributions.

86-02   HISTORICAL ANALYSIS OF THE EFFECT   Yoav Benjamini
OF CLOUD SEEDING ON RUNOFF: Camil Fuchs
CONDITIONAL VS UNCONDITIONAL ANALYSIS

Abstract - Randomized cloud seeding experiments had been conducted in Israel since the early sixties. The decision, based on the analysis of rainful data, was to seed operationally every possible day. In this article we present a method to study the effect of cloudseeding on the runoff, by a double regression approach that uses historical data on both flow measurements as well as rainfall from target and control areas. It was found that the magnitude of the standard errors of the parameter which measures the effect of seeding on runoff, depend largely on whether the problem is viewed conditionally or unconditionally. As a result, the seeding effect is labeled highly significant or nonsignificant depending on the conditionality assumption. Jackknife and bootstrap estimators of the standard deviation were called for aid and compared with crude straightforward estimators. The performance of the various estimates of the standard deviations, in our situation, was studied using a small simulation study. The results illustrate the contention that in cases in which the investigator is uncertain of the effects of conditionality, the jackknife and the bootstrap present a simple and appealing alternative.

86-03   A PROJECTION DECOMPOSITION FOR BIVARIATE   Allan R. Sampson
DISCRETE PROBABILITY DISTRIBUTIONS   Devendra Chhetry

Abstract - Let $Q = \{\text{Prob}(X = x_i, Y = y_j)\}$ for $x_1 < \cdots < x_m$, $y_1 < \cdots < y_n$. A new matrix decomposition of Q is given in terms of certain projections on linear spaces related to the marginal probabilities. It is shown that this decomposition implies Fisher's canonical decomposition and also a representation important in positive dependence. Additionally considered are applications of these ideas to the concordant monotone correlation, the maximal correlation, and Hotelling's canonical correlation.

86-04   **MONOTONE CORRELATION AND**   Devendra Chhetry
MONOTONE DISJUNCT PIECES   Jan deLeeuw
   Allan R. Sampson

Abstract - Suppose X,Y are random variables taking values on the lattice
$\{x_1 <...< x_m\} \times \{y_1 <...< y_n\}$ with $Q = \{Prob(X=x_i, Y=y_j)\}$. Let $\rho_{CMC}(Q)$ and $\rho_{DMC}(Q)$ be the concordant and discordant monotone correlations defined, respectively, by the maximum and minimum of $\{\rho(f(X),g(Y))\}$ over all f,g increasing with nonzero variances. A number of results concerning $\rho_{CMC}(Q)$ and $\rho_{DMC}(Q)$ and their evaluations are obtained. One result shows that $\rho_{CMC}(Q) = 1$, if and only if Q consists of at least two increasing disjunct pieces, i.e., $Q = Diag(Q_1,Q_2)$. Necessary and sufficient conditions are also given for $\rho_{CMC}(Q) = \rho_{DMC}(Q)$.

86-05   **MAXIMUM LIKELIHOOD ESTIMATIONS IN**   Camil Fuchs
EXTENDED MOVER-STAYER MODELS

Abstract - The discrete time mover-stayer model is a useful model for studying change over time in heterogeneous populations. In this report, an alternative method for obtaining maximum likelihood estimates of the parameters of the mover-stayer model based on the EM algorithm is presented and generalizations of the basic model are considered. The method and the model are illustrated with data from a community based study and changes in mental health status over a one year period.

86-06   **CHARACTERIZATION OF NONHOMOGENEOUS**   Zhaoben Fang
POISSON PROCESSES VIA MOMENT CONDITIONS

Abstract - The property of independent increments is one of the most important for defining both the homogeneous and nonhomogeneous Poisson process.

In this paper we give two ways to relax this requirement and characterize the nonhomogeneous Poisson process by some moment conditions.

One result is that a counting process $\{N(t),t \geq 0\}$ with finite moments of all orders is a nonhomogeneous Poisson process with mean functions $m(t) = EN(t)$ if and only if for any t_i, $i = 1, \ldots ,k$

$$cum (N(t_1), \ldots ,N(t_k)) = \min_{1 \leq i \leq k} EN(t_i)$$

where cum $(\cdot)$ is the joint multivariate cumulant.

A second result is that if increments on any interval are Poisson distributed and an exchangeable condition is assumed then the process is nonhomogeneous Poisson. This extends Renyi's (1967) result.

86-07 ESTIMATION OF MULTIVARIATE DISTRIBUTIONS Allan R. Sampson
UNDER STOCHASTIC ORDERING Lyn R. Whitaker

Abstract - Let F and G be the cdf's of two p-dimensional multivariate distribution, such that F is stochastically larger than G. A straightforward derivation is given of a the generalized maximum likelihood estimators of F and G based on the random samples from each population. An algorithmic approach to computing these estimators is described and motivating numerical examples are discussed. The special case when F and G correspond to multivariate ordinal contingency tables is also presented. The relationship of these to those of Robertson and Wright (Ann. Statist. 2 (1974) 528-534) is considered.

86-08 COMPARISONS OF REPLACEMENT POLICIES Naftali A. Langberg

Abstract - For independent random lifelengths of the units in use stochastic comparisons of the number of failures and removal in [0,s] under age and block replacement policies are performed. A new concept of NBU(NW^{r}J) in sequence is introduced.

87-01 A NONLINEAR AUTOREGRESSIVE MODEL IN DIRICHLET N. A. Langberg
RANDOM VECTORS - THEORY, ESTIMATION, AND PREDICTION D. S. Stoffer

Abstract - We construct a nonlinear autoregressive-type model which can be used for modeling and forecasting vector processes in which the distribution of the random vector at each point in time or space is a Dirichlet distribution. That is, the model is useful for modeling and forecasting vector processes in which the data are proportions and constrained so that the sum of the proportions are equal to one at each point in time or space. Estimators of the parameters of the model are obtained via two different methods. First we obtain maximum likelihood estimators, and then we obtain uniformly minimum variance unbiased estimators of the model parameters. Finally, we present an example of the kind of data that can be handled by the model, and discuss the modeling, estimation and prediction methods for the given data set.

87-02   AN ESTIMATION OF AVAILABILITY OF SERIES SYSTEM   Jie Mi

Abstract - Suppose a system S consists of n s-independent subsystems S_j (j = 1,2, . . . , n) connected in series. Denote the lifetime and repair time of subsystem S_j by U_j and D_j, respectively. Based on the sample of complete periods for each subsystem we give an approximate interval estimate of the stable availability of the system S in three cases: (i) Each U_j and D_j has exponential distribution; (ii) Each U_j is distributed exponentially but each D_j has log-normal distribution; (iii) Both U_j and D_j are distributed according to log-normal law. Also the related asymptotic normality and the rate of convergence are discussed.

87-03   L-SUPERADDITIVE STRUCTURE FUNCTIONS   Henry W. Block
William S. Griffith
Thomas H. Savits

Abstract - Structure functions relate the level of operations of a system as a function of the level of the operation of its components. In this paper structure functions are studied which have an intuitive property, called L-superadditive (L-subadditive). Such functions describe whether a system is more series-like or more parallel-like. L-superadditive functions are also known under the names supermodular, quasi-monotone and superadditive and have been studied by many authors. Basic properties of both discrete and continuous (i.e., taking a continuum of values) L-superadditive structure functions are studied. For binary structure functions of binary values, El-Neweihi (1980) showed that L-superadditive structure functions must be series. This continues to hold for binary valued structure functions even if the component values are continuous (see Proposition 3.1). In the case of non-binary valued structure functions this is no longer the case. We consider structure functions taking discrete values and obtain results in various cases. A conjecture concerning the general case is made

87-04   SETWISE INDEPENDENCE FOR SOME   H. W. Block
DEPENDENCE STRUCTURES   Z. Fang

Abstract - Characterization problems of setwise independence are considered by introducing the setwise dependence class $SM_k(n)$.
Two questions are answered: (i) Under which conditions are a strongly positive orthant dependence random vector setwise independent; (ii) Under what kind of dependence structure does a block diagonal Covariance matrix imply setwise independence. The techniques involved in dealing with the above questions allow us to answer some open problems involving the SPOD class raised in Newman (1984).

87-05 CONCEPTS OF SETWISE DEPENDENCE D. Chhetry
G. Kimeldorf
A. R. Sampson

Abstract - This paper motivates and introduces a number of new concepts of positive dependence among sets of random variables. In particular, setwise positive upper (and lower) orthant dependence, setwise association and other related concepts are studied and their relationships are explored. These new concepts are applied to various multivariate normal distributions, some of which have both positive and negative covariances. A variety of new and interesting inequalities are also obtained.

87-06 A COST RELATIONSHIP BETWEEN T. H. Savits
AGE AND BLOCK REPLACEMENT POLICIES

Abstract - The general cost structure of a unit on line is assumed to be governed by a stochastic process $\{R(t), 0 \leq t \leq \zeta\}$, where $R(t)$ denotes the operating cost on $[0,t)$ and ζ denotes the time of an unscheduled (or unplanned) replacement by a new unit at a cost c_1. For an age replacement maintenance policy, scheduled (or planned) replacements occur whenever an operating unit reaches age T, whereas in the block replacement case, scheduled replacements occur every T units of time. Such scheduled replacements cost c_2. The expected long run cost per unit time can then be expressed in the form $A(T)/E[\min(\zeta, T)]$ and $B(T)/T$ respectively. Our main result shows that
$B(T) = \int_{\{0,T)} A(T-x) \, dU(x)$ where U is the associated renewal function generated by ζ.

87-07 NONLINEAR MODELS FOR TIME SERIES WITH ARBITRARY N. A. Langberg
CONTINUOUS MARGINAL PREDICTION - THEORY, D. S. Stoffer
ESTIMATION AND PREDICTION

Abstract - In this paper we present a general method for analyzing stationary time series with arbitrary continuous marginal distributions. Both a nonparametric approach (when the distribution is unspecified) and a parametric approach (when the distribution is specified) are taken. The models which we construct are nonlinear models that are obtained by a monotone nondecreasing transformation of a Gaussian linear process. We discuss the estimation and prediction procedures for both the nonparametric and parametric models and apply both approaches to a real data set.

87-08   A MULTIPLE COMPARISONS PROCEDURE FOR USE IN   P. K. Norwood
             CONJUNCTION WITH THE BENARD-VAN ELTEREN TEST   A. R. Sampson
                                                      R. Staum
                                                      K. McCarroll

Abstract - The Bernard-van Elteren test statistic is a generalization of the Friedman test statistic which permits multiple and unequal replicates per treatment per block. A multiple comparisons procedure developed by Nemenyi, based on the Friedman rank sums, is extended for the pairwise comparisons of treatments in conjunction with the Benard-van Elteren test. This procedure is applied to an example arising from a clinical trial. A necessary and sufficient condition for use of this multiple comparisons procedure is given, with examples of designs for which this condition is met. This multiple comparisons procedure is shown to be identical to the Nemenyi procedure for the RCB design with one replicate per treatment per block, and to a procedure given by Campbell for the BIB design.

87-09   PARTIAL ORDERS ON PERMUTATIONS AND DEPENDENCE   H. W. Block
           ORDERINGS ON BIVARIATE EMPIRICAL DISTRIBUTIONS   D. Chhetry
                                                         Z. Fang
                                                        A. R. Sampson

Abstract - Three well known partial orderings and one new one, designated by $\overset{b_t}{\geq}$, $t = 1,2,3,4$ are defined on permutations of $\{1,2....,n\}$ through a unified approach. Various formulations of these partial orderings are also considered. With the aid of these formulations, we show that the four orderings on permutations are equivalent to positive dependence orderings defined over empirical distributions based on rank data. In particular, we show that the orderings b_1, b_2, b_3 and b_4 are equivalent, respectively, to more concordant, more row regression dependent, more column regression dependent and more associated.

87-10   IMPROVED RELIABILITY BOUNDS FOR SYSTEMS   Zhaoben Fang
                        WITH DEPENDENT COMPONENTS

Abstract - Improved reliability bounds for systems with dependent components are obtained by investigating the multivariate probability inequalities under associated or strongly positive orthant dependence (SPOD) assumptions. Using information on correlatedness for different path sets (or cut sets) and covariances between different components more accurate reliability bounds are obtained. The reliability bounds for a system can also be improved by an adaptable probability inequality (Theorem 1 in paper). A numerical example is given to show the improvements.

87-11   METRICS ON PERMUTATIONS BASED   H. W. Block
              ON PARTIAL ORDERINGS   D. Chhetry
                                                Z. Fang
                                                A. R. Sampson

Abstract - For two permutations **i** and **j** of the integers 1, . . . , n, a number of different metrics between **i** and **j** are studied in a unified fashion. Attention is focused on two new metrics and on three previously studied metrics. The new metrics are related to the more associated partial ordering between pairs of bivariate random vectors. Results are also given connecting these metrics to a number of previously considered partial orderings on the set of all permutations of 1, . . . , n.

**87-12   A REVIEW OF MULTIVARIATE INTERPRETATION OF   A. R. Sampson
            CLINICAL LABORATORY DATA**

Abstract - This is a review for the *Journal of the American Statistical Associaton* of *Multivariate Interpretation of Clinical Laboratory Data* written by A. Albert and E. K. Harris (1987).

88-01   A DISCOUNTED COST RELATIONSHIP   C. S. Chen
                                                T. H. Savits

Abstract - In Savits (1987) a very general cost mechanism for a maintained system was considered. There he established a relationship between the expected long run cost per unit time for the age and block maintenance policies. In the present paper a similar relationship is obtained for the expected total α-discounted cost.

**88-02   EXACT POWER AND SAMPLE SIZE CALCULATIONS   C. Gatsonis
            FOR OBSERVATIONAL STUDIES   A. R. Sampson**

Abstract - In observational studies it is often the case that the values of the independent variables cannot be fixed in advance but are themselves outcomes of the study. Power and sample size calculations should take this source of variability into account, since they have to be done before the data become available. This article reviews the mathematical framework for studies in which a multivariate normal distribution can be assumed jointly for the dependent and independent variables under observation. Within this framework, exact power and sample size calculations can be done using a series expansion for the distribution of the sample multiple correlation coefficient. A new table of exact samples sizes for tests of level .05 is provided here. Approximations to the exact power are discussed, most notably those of Cohen, 1977. A rigorous justification for Cohen's approximations is given. Comparisons with the exact answers show that the approximations are quite accurate in many situations of practical interest. More extensive tables and an interactive computer program for both exact power and sample size computations can be obtained directly from the authors.

88-03   COMPUTATIONAL ASPECTS OF ASSOCIATION FOR   A. R. Sampson
          BIVARIATE DISCRETE DISTRIBUTIONS   L. R. Whitaker

Abstract For bivariate discrete probability distributions, P, on the $M \times N$ lattice, various aspects for checking association (Esary, Proschan and Walkup (1967)) are considered. A new algorithm is given for verifying whether or not P is associated. The efficiency of this algorithm is obtained and compared to the efficiency of a simple algorithm based on the definition of association. When $M = N = 4$, for example, the new algorithm requires less then 3% of the computations required for the simple algorithm. In obtaining these results a new set function Q is constructed from P, on all upper sets in the lattice. In order to construct the algorithm to check association, we define a computationally important set of extreme points and consider related combinatorics.

88-04   CHARACTERIZING AND GENERATING BIVARIATE   M. H. Metry
          EMPIRICAL RANK DISTRIBUTIONS SATISFYING   A. R. Sampson
          CERTAIN POSITIVE DEPENDENCE CONCEPTS

Abstract - Let $i = (i_1, \ldots, i_N)$ be a permutation in S_N, the set of all permutations of $\{1, \ldots, N\}$ and define a related bivariate random vector (R, S) by $P(R = k, S = i_k) = N^{-1}$, $k = 1, \ldots, N$. A permutation i is said to have a given positive dependence property if the related random vector has that property. We show i is a PQD permutation if $i_{l,k} \geq (l/k)N$, for all $l = 1, \ldots, k$ and all $k = 1, \ldots, N - 1$, where $i_{1,k} < i_{2,k} < \cdots < i_{k,k}$; $k = 1, \ldots, N - 1$ are the increasing rearrangements of $i_{N-k+1}, i_{N-k+2}, \ldots, i_N$. Additionally, we show $i = (1, \ldots, N)$ is the only permutation which is any of TP_2, SI, RCSI, LTD or RTI. Explicit techniques for iteratively characterizing PQD permutations are obtained and used to count the number of PQD permutations in S_N. Based on these techniques, graph theoretic methods are used to generate all PQD permutations on S_N. Similar results for related dependence notions are also given.

88-05   DUAL QUALITY CONTROL FOR THE CYTOLYTIC ASSAY   R. Day
                                                        J. Bryant
                                                        T. Whiteside

Abstract - The cytolytic assay performed at the Pittsburgh Cancer Institute is described and discussed. The desirability of a convenient method to adjust assay data for systematic daily variation is documented, and several such methods are compared. These include naive adjustments obtained by computing the difference of the daily mean of frozen control specimens and their corresponding long-term mean, use of an ad-hoc shrinking constant determined by fitting fresh data to frozen controls by least squares, and computation of adjustments based on empirical Bayes methods and EM algorithm. Although final conclusions have yet to be drawn concerning the latter two methods, it appears that the naive estimator rather seriously over-adusts the data.

88-06   STOCHASTIC COMPARISONS: BLOCK POLICIES   H. W. Block
N. A. Langberg
T. H. Savits

Complete repair and minimal repair models with a block maintenance policy are considered. Each of these models gives rise to a counting process and these processes are compared stochastically. This contrasts with most previous work on maintenance policies where only univariate marginal comparisons were made. Also a more general block schedule is considered than is customary.

88-07   OPTIMAL PRODUCT-TYPE PROBABILITY BOUNDS   H. W. Block
T. Costigan
A. R. Sampson

Abstract - The usual second order product- type approximation to $P_n = P(X_1 \leq c_1, X_2 \leq c_2,....,X_n \leq c_n)$ is defined as $\beta_2 = \prod_{i=2}^{n} P(X_{i-1} \leq c_{i-1}, X_i \leq c_i) / \prod_{i=2}^{n-1} P(X_i \leq c_i)$. In this paper, techniques of graph theory are used to obtain a class of more general product-type probability approximations, analogous to Hunter's second order Bonferroni-type bounds. For any spanning tree, T, of the complete graph with vertex set $V = \{1, \ldots, n\}$, the second order product-type approximation corresponding to T, $\beta_2(T)$ is defined as

$$\beta_2(T) = \prod_{(i,j) \in T} P(X_i \leq c_i, X_j \leq c_j) / \prod_{i=1}^{n} P(X_i \leq c_i)]^{d_i - 1},$$

where d_i is the degree of i in T.

It is shown that Kruskal's maximal spanning tree algorithm applied to the network function $f(e_{ij}) = P(X_i \leq c_i, X_j \leq c_j)/[P(X_i \leq c_i) \cdot P, (X_j \leq c_j)]$ yields the spanning tree, T_0, which maximizes $\beta_2(T)$ among all spanning trees.

For multivariate normal distributions a simple bound condition which guarantees that $P_n \geq \beta_2(T)$ is obtained by using Worsley's increasing representation of spanning trees.

It is also shown that when applicable, the second order product-type bound corresponding to T, $\beta_2(T)$, is sharper than the second order Bonferroni-type bound of Hunter and Worsley. This allows us to obtain sharper bounds than those previously proposed for the detection of a change point. Additional applications considered include autoregressive correlation models, modeling communication networks, multiple comparisons to a control and successive differences in population means.

88-08   **PRODUCT-TYPE PROBABILITY BOUNDS OF HIGHER ORDER**   H. W. Block
T. Costigan
A. R. Sampson

Abstract - Glaz and Johnson introduce i-th order product-type approximations, β_i, $i = 1, \ldots, n - 1$, for $P_n = P(X_1 \leq c_1, X_2 \leq c_2, \ldots, X_n \leq c_n)$ and show that $P_n \geq \beta_{n-1} \geq \beta_{n-2} \geq \cdots \geq \beta_2 \geq \beta_1$ when $\underline{X}$ is MTP_2. In this article, it is shown that $P_n \geq \beta_2 = \prod_{i=2}^{n} P(X_{i-1} \leq c_{i-1}, X_i \leq c_i) / \prod_{i=2}^{n-1} P(X_i \leq c_i) \geq \beta_1 = \prod_{i=1}^{n} P(X_i \leq c_i)$ under weaker positive dependence conditions. For multivariate normal distributions, these conditions reduce to $COV(X_i, X_j) \geq 0$ for $1 \leq i < j \leq n$ and $COV(X_i, X_j | X_{j-1}) \geq 0$ for $1 \leq i < j - 1$, $j = 3, \ldots, n$. It is shown that $P_n \geq \beta_2 \geq \beta_1$ when group sequential analysis is performed for bivariate normal responses.

Conditions for $P_n \geq \beta_3 \geq \beta_2 \geq \beta_1$ are also derived.

Bound conditions are also obtained which insure that product-type approximations are nested lower bounds to upper orthant probabilities $P(X_1 > c_1, \ldots, X_n > c_n)$. It is shown that these conditions are satisfied for the multivariate exponential distribution of Marshall and Olkin.

88-09   **POSITIVE DEPENDENCE CONCEPTS FOR MULTIVARIATE**   M. H. Metry
EMPIRICAL RANK DISTRIBUTIONS   A. R. Sampson

Abstract - The study of positive dependence notions for bivariate empirical rank distributions can be viewed mathematically as the study of partial orderings on the set, S_N, of permutations of $\{1, \ldots, N\}$. This paper extends many of the previously obtained bivariate results to cases of multivariate empirical rank distributions, with primary focus on the trivariate case. Mathematically, this can be reduced to studying notions of positive dependence on the space $S_N \times S_N$ via the concept of related random vectors, where a trivariate random variable (R, S, T) is said to be related to $(i, j) \in S_N \times S_N$ if $P(R = k, S = i_k, T = j_k) = N^{-1}$, for all $k = 1, \ldots, N$. Characterizations of the positive dependence properties: PUOD, PLOD and POD are obtained in terms of a newly defined notion of a relative increasing rearrangement. Also, characterization of the positive dependence orderings: more PUOD, more PLOD and more POD are obtained by comparing certain relative rearrangements. By our results and certain bivariate results, a new partial ordering describing concordance on $S_N \times S_N$ is introduced. Its connection with the orderings more PUOD, more PLOD, and more POD is established.

88-10   SOME NEW PARTIAL ORDERINGS ON S_n and   H.W. Block
$$S_n \times S_n$$
D. Chhetry
Z. Fang
A.R. Sampson

Abstract - A new class of partial orderings on S_n, the set of permutations of $\{1, \ldots, n\}$, is given. Each of these partial orderings is shown to be a subordering of a recently described partial ordering on S_n (Block, Chhetry and Sampson (1987)) which is related to Schriever's *(Annlas of Staistics,* 1987) more associated ordering on bivariate distributions. Also given is an extension of three known partial orders on S_n to partial orders on $S_n \times S_n$. These extensions facilitate the study of functions from $S_n \times S_n$ into **R**, which preserve these partial orderings, thereby, providing a methodology for extending the notion of arrangement increasing functions.

89-01   LIMITING DISTRIBUTIONS FOR STATISTICS BASED   S.K. Bar-Lev
ON DIFFERENT SAMPLES   N.A. Langberg
B. Reiser

Abstract - Let $\underline{A}_m$ and $\underline{B}_n$ be two k-dimensional statistics based on independent samples of sizes m and n, respectively, from two populations, and let $\underline{f}$ be a vector valued function defined on the 2k-th Euclidean space. This paper deals with the limiting distribution function of $\underline{f}(\underline{A}_m, \underline{B}_n)$, suitably normalized, as m and n tend to infinity separately. Applications to estimation and hypothesis testing problems are given. The connection between these results and those previously obtained in the literature is discussed.

89-02   SEQUENCING OF EXPERIMENTS FOR LINEAR AND   J. Bryant
QUADRATIC TIME EFFECTS   G. Constantine

Abstract - Run orders that are optimal against a linear time trend and efficient against quadratic trend are constructed. The emphasis is on settings that allow d replications on each of m treatments. A description of the linearly optimal and quadratically most efficient sequences is also given. Explicit formulae are found, along with asymptotic bounds, for the efficiency of the sequences constructed.

89-03 OPTiMAL REPLACEMENT FOR A GENERAL MAINTENANCE MODEL   C.S. Chen
T.H. Savits

Abstract - We continue the study of our general cost structure for a maintenance system. Here we focus on the optimization questions. The notion of a marginal cost function is rigorously formulated and its utility investigated. Various applications are considered including a new model in which minimal repairs are performed as long as the total repair costs do not exceed a fixed amount.

89-04   A NOTE ON CHARACTERIZATION OF A MULTIVARIATE   T.T. Nguyen
                    STABLE DISTRIBUTION   A.R. Sampson

Abstract - Several characterization of multivariate stable distributions together with a characterization of multivariate normal distributions and multivariate stable distributions with Cauchy marginals are given. These are related to some standard characterizations of Marcinkiewicz.

89-05   SECOND ORDER BONFERRONI-TYPE, PRODUCT-TYPE AND   H.W. Block
                AND SETWISE PROBABILITY INEQUALITIES   T. Costigan
                                                          A.R. Sampson

Abstract: This review paper considers a variety of lower bounds to $\text{Prob}[X_1 \leq c, \ldots, X_n \leq c]$ involving one and two dimensional marginal distributions. Some of these bounds, e.g., Bonferroni-type, do not require conditions on the random variables. Others of these inequalities, e.g., product-type, require positive dependence conditions on $X_1, \ldots, X_n$ for the inequalities to hold. Because all of the two dimensional bounds depend on the labeling order of the random variables, various permutation-optimized versions of the bounds are described. Relationships among the various bounds are also considered.

89-06   REPAIR POLICIES AND STOCHASTIC ORDER   T.H. Savits

Abstract - This paper reviews the role of stochastic order as it relates to the study of maintained systems in reliability theory. The classical univariate comparison results for the age and block replacement policies are presented. Extensions to stochastic comparison of processes and recent generalizations of age and block policies are also discussed.

89-07   REPAIR REPLACEMENT POLICIES   H.W. Block
                                                          N.A. Langberg
                                                          T.H. Savits

Abstract - In this paper we introduce the concept of repair replacement. Repair replacement is a maintenance policy in which items are preventively maintained when a certain time has elapsed since their last repair. This differs from age replacement where a certain amount of time has elapsed since the last replacement. If the last repair was a complete repair, repair replacement is essentially the same as age replacement. It is in the case of minimal repair that these two policies differ. We then make comparison between various types of policies in order to determine when and under which condition one type of policy is better than another.

4. PUBLICATION OF REPORTS

1984

REPORT NO.

84-01 A. R. Sampson and G. Kimeldorf. A framework for positive dependence *Ann. Inst. Statist. Math A.* **39** (1987). 113-128.

84-02 H. W. Block, V. Bueno, T. H. Savits and M. Shaked. Probability inequalities via negative conditioned on order statistics. *Naval Research Logistics Quarterly* **34** (1987), 547-554.

84-03 H. W. Block, T. H. Savits and M. Shaked. A concept of negative dependence using stochastic ordering. *Statistics and Probability Letters* **3** (1985), 81-86.

84-04 H. W. Block, W. S. Borges and T. H. Savits. Age dependent minimal repair. *J. of Appl. Prob.* **22** (1985), 370-385.

84-05 T. H. Savits and E. El-Neweihi. Convolution of the IFRA scaled-mins class. *Ann. Prob.,* **15** (1987), 423-427.

1985

85-01 T. H. Savits and H. W. Block. Multivariate nonparametric classes in reliability. *Handbook of Statistics,* V. 7 (Eds. P. R. Krishnaiah and C. R. Rao), Elsevier, 1988, 121-129.

85-02 D. S. Stoffer and N. A. Langberg. Moving average models with bivariate exponential and geometric distributions. *J. of Appl. Prob.* **24** (1987), 48-61.

85-03 A. R. Sampson and C. Fuchs. Simultaneous confidence intervals for the general linear model. *Biometrics* **43**, 457-469.

85-04 S. May. Ordinal log-linear models and the TMI data. Unpublished.

85-05 H. W. Block and A. R. Sampson. Conditionally ordered distributions. *J. Mult. Anal.* **27** (1988), 91-104.

85-06 S. May. Modelling Inter-rater Agreement. with ordinal log-linear models. Unpublished.

85-07 T. H. Savits. Some multivariate distributions derived from a nonfatal shock model. *J. Appl. Prob.* **25** (1988), 383-390.

85-08 C. Fuchs and R. Kenett. Multivariate tolerance regions and F-tests. (submitted)

85-09　J. May and A. R. Sampson. Merging dissimilar ordinal categorical judgements. *Proceedings of the International Conference on the Advances in Multivariate Analysis, to appear.*

85-10a　A. R. Sampson and L. Whitaker. Positive dependence, upper sets, and multidimensional partitions. *Mathematics of Operations Research* 3 (1988), 254-264.

85-10b　H. W. Block and Z. Fang. A multivariate extension of Hoeffding's lemma. *Ann. Prob.* 16 (1988), 1803-1820.

85-11　C. Fuchs. Adenoidectomy versus FT/C. (submitted)

85-12　C. Fuchs. Evaluation of scientific information. Unpublished.

85-13　A. R. Sampson and D. S. Stoffer. An interpretative framework for regression and linear prediction. (submitted)

85-14　N. A. Langberg and O. Stramer. On the linear exponential family. with a quadractic variance function. (submitted)

1986

86-01　H. W. Block, N. A. Langberg and D. S. Stoffer. Bivariate exponential and geometric autoregressive and autoregressive moving average models. *Adv. Appl. Prob.*, 20 (1988), 798-821.

86-02　Y. Benjamini and C. Fuchs. Historical analysis of effect of cloud seeding on runoff: Conditional vs Unconditional Analysis. (submitted)

86-03　D. Chhetry and A. R. Sampson. A projection decomposition for bivariate discrete probability distribution. *SIAM Journal of Algebraic and Discrete Mathematics* 8 (1987), 501-509.

86-04　D. Chhetry, J. de Leeuw and A. R. Sampson. Monotone correlation and monotone disjunct pieces. (submitted).

86-05　C. Fuchs. Maximum likelihood estimation in extended mover-stayer models. (submitted).

86-06　Z. Fang. Characterization of nonhomogeneous Poisson processes via moment conditions. (submitted).

86-07　A. R. Sampson and L. Whitaker. Estimation of multivariate distributions under stochastic ordering. *J. Amer. Statist. Assoc.*, 84 (1989), 541-548.

86-08　N. A. Langberg. Comparisons of replacement policies. To appear in *Journal of Applied Probability.*

1987

87-01   N. A. Langberg and D. S. Stoffer.   A nonlinear autoregressive model in Dirichlet random vectors - theory, estimation, and prediction. To be published in the *Proceedings of the Conference on Dependence in Statistics and Probability*.

87-02   J. Mi.   An interval estimation of availability of series system. (submitted).

87-03   H. W. Block, W. S. Grifith and T. H. Savits. L-superadditive structure functions. To appear in *Advances in Applied Probability*.

87-04   H. W. Block and Z. Fang. Setwise independence for some dependence structures. To appear in *Journal of Multivariate Analysis*.

87-05   D. Chhetry, G. Kimeldorf, and A. R. Sampson. Concepts of setwise dependence. Accepted subject to revision in *Probability in the Engineering and Information Sciences*.

87-06   T. H. Savits. A cost relationship between age and block replacement policies. *J. Appl. Prob.*, to appear.

87-07   N. A. Langberg and D. S. Stoffer. Nonlinear models for time series with arbitrary continuous marginal distributions - Theory, estimation and prediction. To be published in the *Proceedings of the Conference on Dependence in Statistics and Probability*.

87-08   P. K. Norwood, A. R. Sampson, R. Staum, K. McCarroll. A multiple comparisons procedure for use in conjunction with the Bernard-van Elteren Test. Under revision for *Biometrics*.

87-09   H. W. Block, D. Chhetry, Z. Fang, and A. R. Sampson. Partial orders on permutations and dependence orderings on bivariate emperical distributions. Under revision for *Annals of Statistics*.

87-10   Z. Fang. Improved reliability bounds for systems with dependent components. (submitted).

87-11   H. W. Block, D. Chhetry, Z. Fang, and A. R. Sampson. Metrics on permutations based on partial orderings. (submitted).

87-12   A. R. Sampson. Book Review of "A Review of Multivariate Interpretation of Clinical Laboratory Data." *Journal of the American Statistical Association* **83** (1988), 577-578.

1988

88-01   C. S. Chen and T. H. Savits. A discount cost relationship. *J. Mult. Anal.*, (1988), to appear.

88-02   C. Gatsonis and A. R. Sampson. Exact power and sample size calculations for observational studies. To appear in *Psychological Bulletin*.

88-03   A. R. Sampson and L. R. Whitaker. Computational aspects of association for bivariate discrete distributions. *Contributions to Probability and Statistics Essays in Honor of Ingram Olkin* (1989), to appear.

88-04   M. H. Metry and A. R. Sampson. Characterizing and generating bivariate empirical rank distributions satisfying certain positive dependence concepts. (submitted).

88-05   R. Day, J. Bryant and T. Whiteside. Data quality control for the cytolytic assay. Unpublished.

88-06   H. W. Block, N. A. Langberg, and T. H. Savits. Stochastic comparisons: block policies. (submitted).

88-07   H. W. Block, T. Costigan, and A. R. Sampson. Optimal product-type probability bounds. (submitted).

88-08   H. W. Block, T. Costigan, and A. R. Sampson. Product-type probability bounds of higher order. (submitted).

88-09   M. H. Metry and A. R. Sampson. Positive dependence concepts for multivariate empirical rank distributions. (submitted).

88-10   H. W. Block, D. Chhetry, Z. Fang, and A. R. Sampson. Some new partial orderings on S_n and $S_n \times S_n$. (submitted).

Other published papers supported, in part, by AFOSR Grant 84-0113, not issued as Technical Reports.

1987   D. S. Stoffer. Walsh-Fourier analysis of discrete-valued time series. *Journal of Time Series Analysis, Vol. 8*, 449-467.

1987   D. S. Stoffer and T. Panchalingan. A Walsh-Fourier approach to the analysis of binary time series. *Time Series and Econometric Modelling, Vol. III*, 147-163.

1988   D. S. Stoffer, M. Scher, G. Richardson, N. Day, and P. Coble. A Walsh-Fourier analysis of the effects of moderate maternal alcohol consumption on neonatal sleep-state cycling. *JASA* (1988).